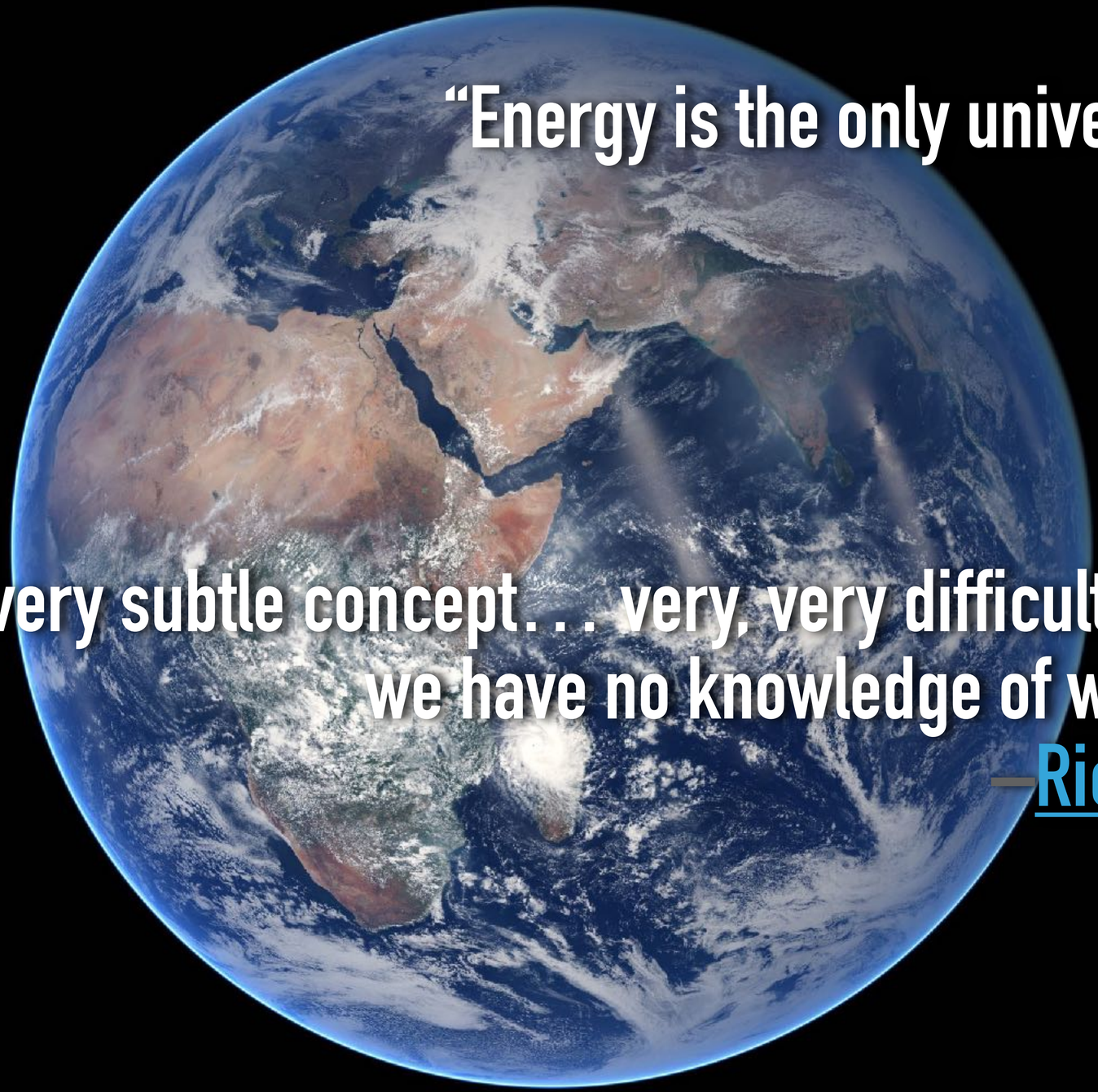
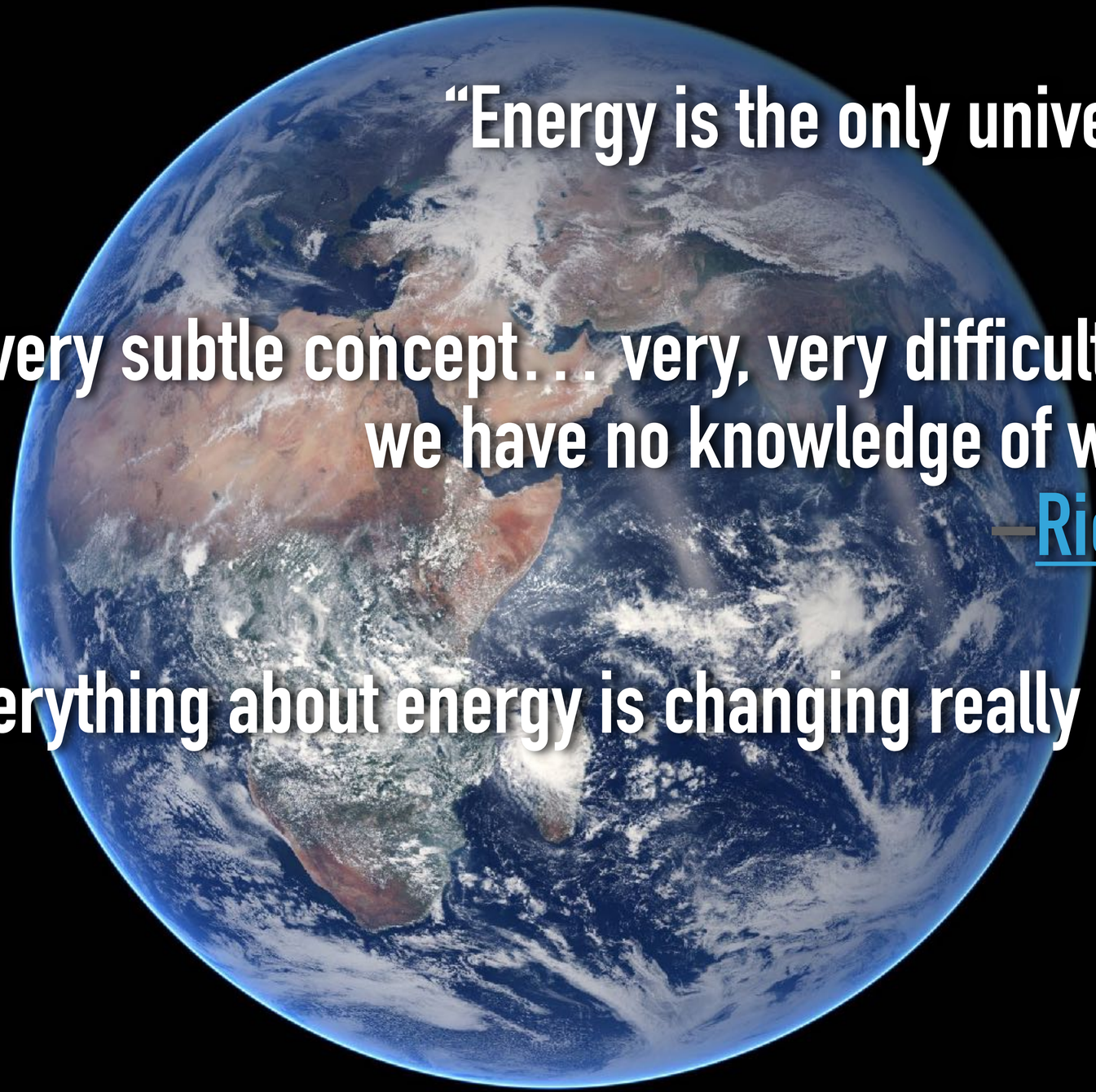
14 week course notes:
fddrsn.net/teaching/energy



"Energy is the only universal currency."
—Vaclav Smil

"Energy is a very subtle concept… very, very difficult to get right…
we have no knowledge of what energy is."
—Richard Feynman



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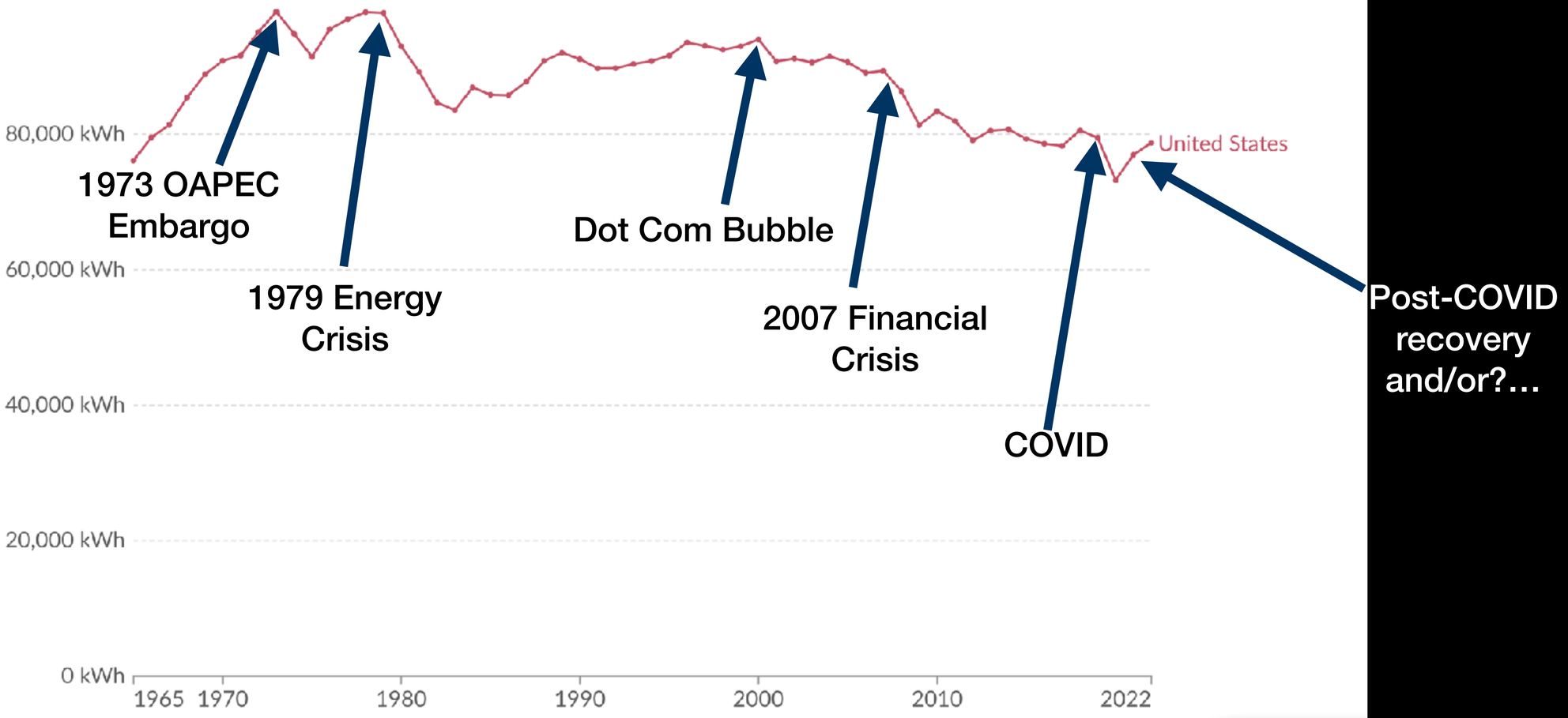
Everything about energy is changing really fast, right now!
—Me!

Energy use per person

Measured in kilowatt-hours[1] per person. Here, energy refers to primary energy[2] using the substitution method[3].

Our World in Data



Data source: U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2023); Popu
based on various sources (2023)

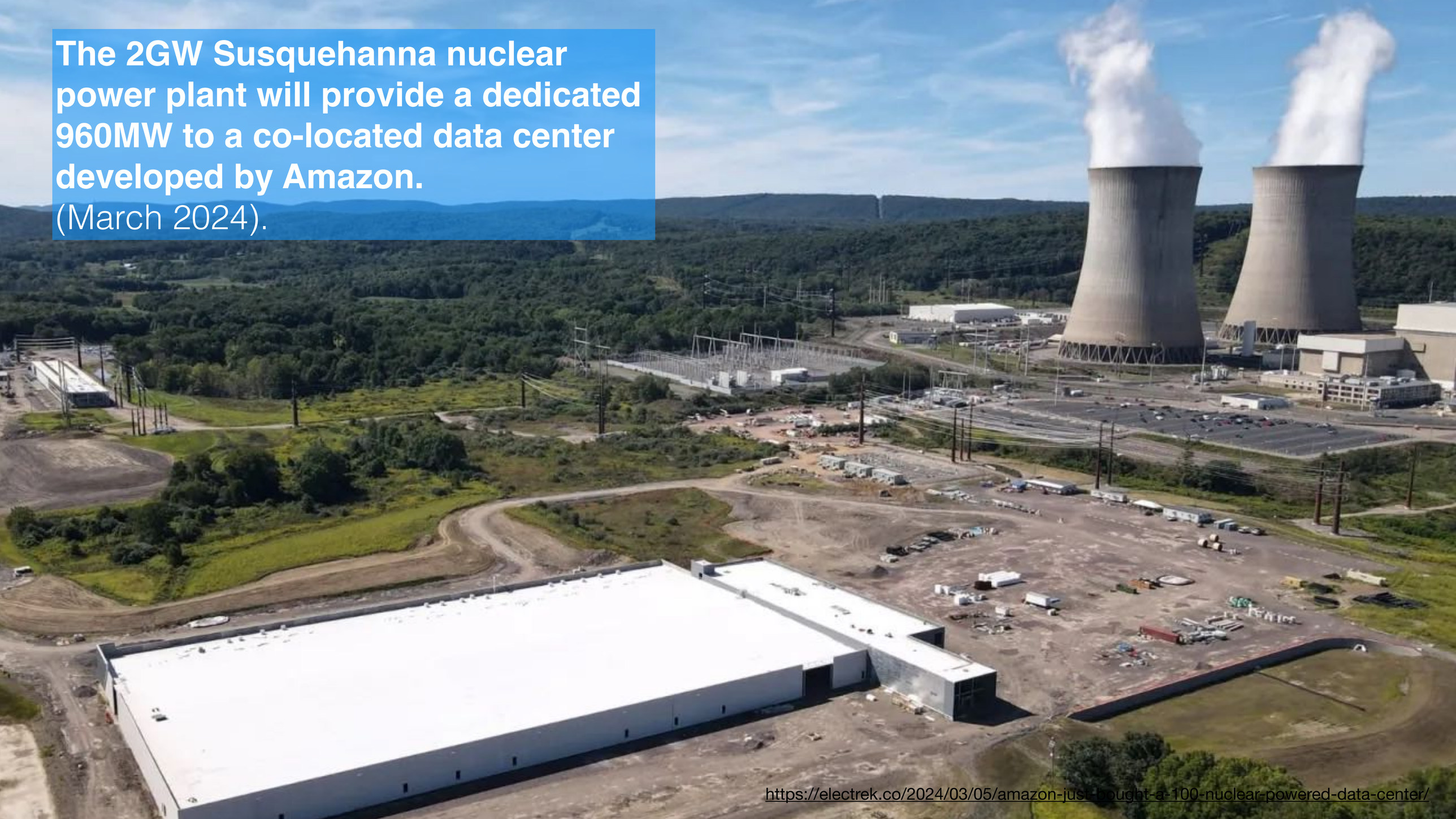
OurWorldInData.org/energy | CC BY

1. Watt-hour: A watt-hour is the energy delivered by one watt of power for one hour. Since one watt is equivalent to one joule per second, a watt-hour is equivalent to 3600 joules of energy. Metric prefixes are used for multiples of the unit, usually: - kilowatt-hours (kWh), or a thousand watt-hours. - Megawatt-hours (MWh), or a million watt-hours. - Gigawatt-hours (GWh), or a billion watt-hours. - Terawatt-hours (TWh), or a trillion watt-hours.

2. Primary energy: Primary energy is the energy available as resources – such as the fuels burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil. Primary energy includes energy that the end user needs, in the form of electricity, transport and heating, plus inefficiencies and energy that is lost when raw resources are transformed into a usable form. You can read more on the different ways of measuring energy in our article.

3. Substitution method: The 'substitution method' is used by researchers to correct primary energy consumption for efficiency losses experienced by fossil fuels. It tries to adjust non-fossil energy sources to the inputs that would be needed if it was generated from fossil fuels. It assumes that wind and solar electricity is as inefficient as coal or gas. To do this, energy generation from non-fossil sources are divided by a standard 'thermal efficiency factor' – typically around 0.4 Nuclear power is also adjusted despite it also experiencing thermal losses in a power plant. Since it's reported in terms of electricity output, we need to do this adjustment to calculate its equivalent input value. You can read more about this adjustment in our article.

ELECTRIFY EVERYTH DECARBO ELECTRI


The 2GW Susquehanna nuclear power plant will provide a dedicated 960MW to a co-located data center developed by Amazon.
(March 2024).
https://electrek.co/2024/03/05/amazon-just-bought-a-100-nuclear-powered-data-center/


itp
CAMP

itp CAMP

Camp goals:

- Gain a better understanding of the concepts “energy” and “power”
- Learn and use their units
- Perform basic energy calculations
- Apply those concepts to real-life

Definitions (from Oxford Dictionary of Physics):

Energy

A measure of a system’s ability to do work.

Like work itself, it is measured in joules. Energy is conveniently classified into two forms: potential energy is the energy stored in a body or system as a consequence of its position, shape, or state (this includes gravitational energy, electrical energy, nuclear energy, and chemical energy); kinetic energy is energy of motion and is usually defined as the work that will be done by the body possessing the energy when it is brought to rest. For a body of mass m having a speed v, the kinetic energy is mv2/2 (classical) or (m–m0)c2 (relativistic). The rotational kinetic energy of a body having an angular velocity ω is Iω2/2, where I is its moment of inertia.

The internal energy of a body is the sum of the potential energy and the kinetic energy of its component atoms and molecules.

It is a fundamental feature of physics that energy is always conserved in any process. It has occasionally been suggested in various contexts that energy is not conserved, but these suggestions have always turned out to be incorrect.

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Work

The work done by a force acting on a body is **the product of the force and the distance moved** by its point of application in the direction of the force. If a force F acts in such a way that the displacement s is in a direction that makes an angle θ with the direction of the force, the work done is given by: W=F.scosθ. Work is the scalar product of the force and displacement vectors. It is measured in joules.

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Joule = the SI* unit for Energy

*from French Système international d'unités

Activity: What did you eat today?

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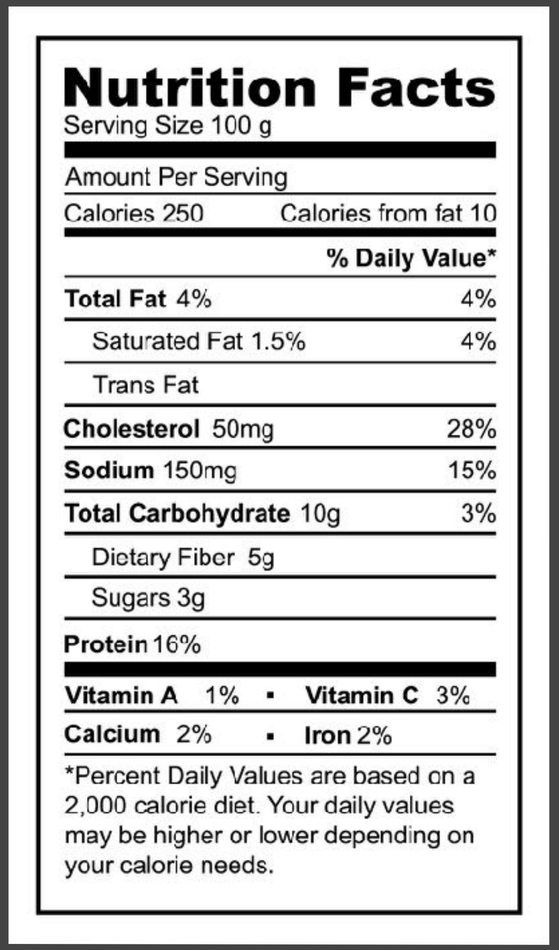


Nutrition Facts

Serving Size 100 g

Amount Per Serving

Calories 250 Calories from fat 10

	% Daily Value*
Total Fat 4%	4%
Saturated Fat 1.5%	4%
Trans Fat	
Cholesterol 50mg	28%
Sodium 150mg	15%
Total Carbohydrate 10g	3%
Dietary Fiber 5g	
Sugars 3g	
Protein 16%	

Vitamin A 1% • **Vitamin C** 3%

Calcium 2% • **Iron** 2%

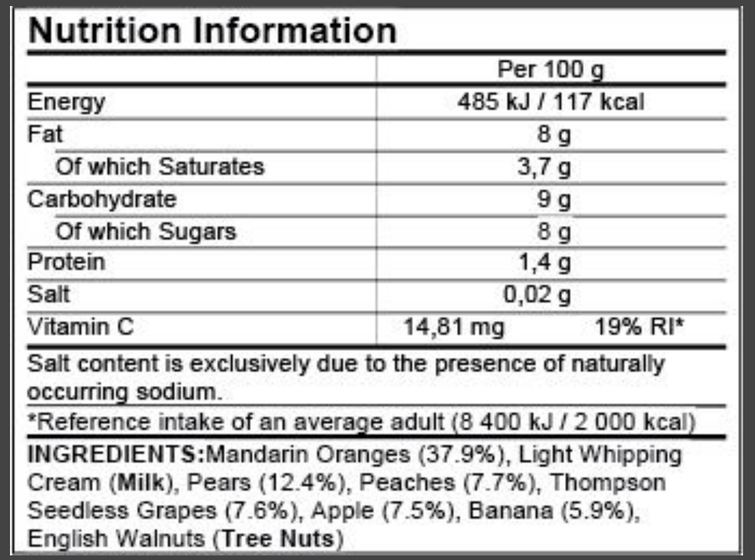
*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

US

营养成分表

项目	每100ml	NRV%
能量	284kJ	3%
蛋白质	3.1g	5%
脂肪	3.7g	6%
碳水化合物	4.8g	2%
钠	62mg	3%
钙	100mg	13%

China



Nutrition Information

	Per 100 g	
Energy	485 kJ / 117 kcal	
Fat	8 g	
Of which Saturates	3,7 g	
Carbohydrate	9 g	
Of which Sugars	8 g	
Protein	1,4 g	
Salt	0,02 g	
Vitamin C	14,81 mg	19% RI*

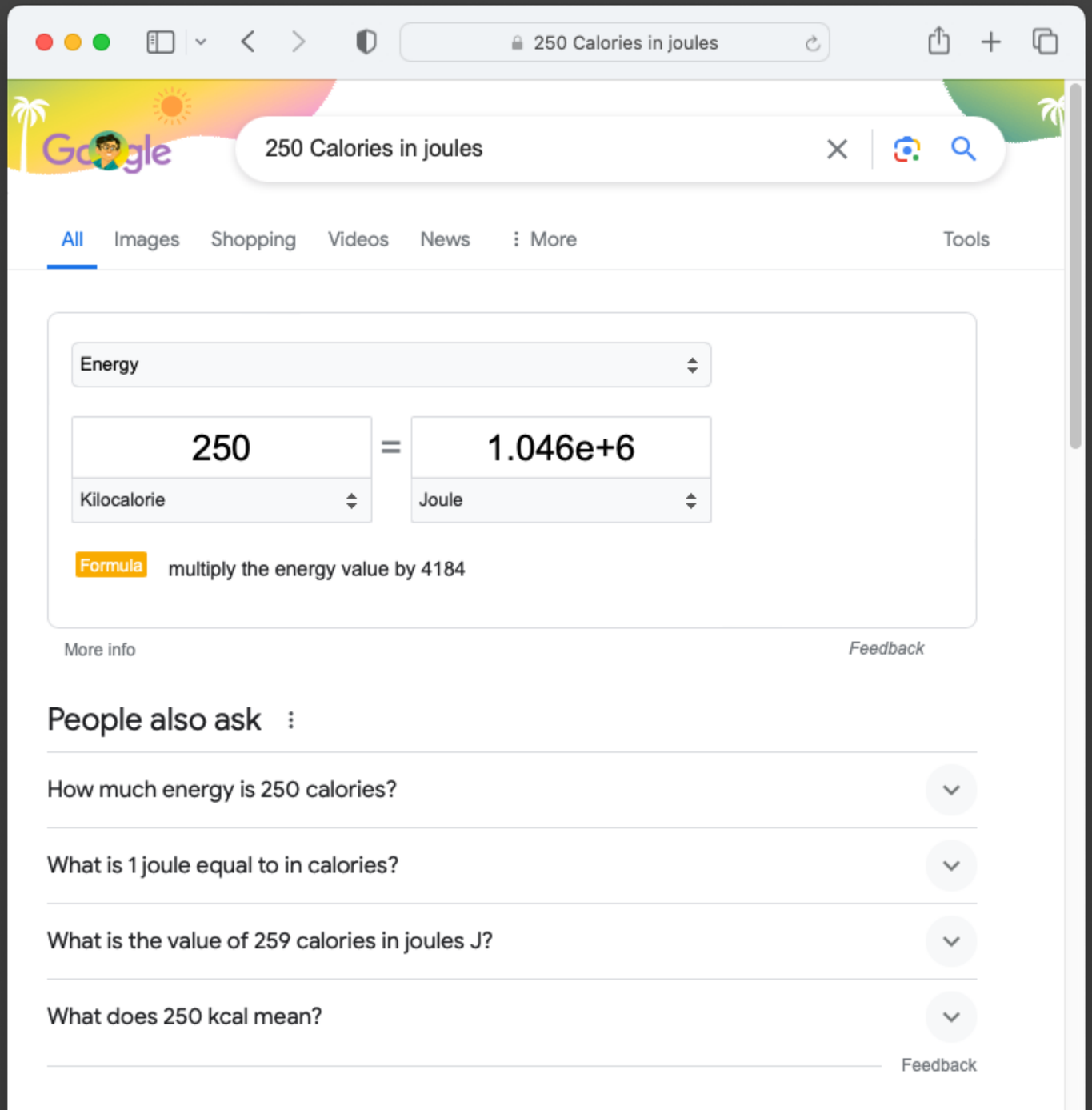
Salt content is exclusively due to the presence of naturally occurring sodium.

*Reference intake of an average adult (8 400 kJ / 2 000 kcal)

INGREDIENTS: Mandarin Oranges (37.9%), Light Whipping Cream (**Milk**), Pears (12.4%), Peaches (7.7%), Thompson Seedless Grapes (7.6%), Apple (7.5%), Banana (5.9%), English Walnuts (**Tree Nuts**)

EU

Try this: Use Google calculator, Wolfram, ChatGPT etc to convert energy units



250 Calories in joules

250 Calories in joules

All Images Shopping Videos News More Tools

Energy

250 = 1.046e+6

Kilocalorie Joule

Formula multiply the energy value by 4184

More info Feedback

People also ask

How much energy is 250 calories?

What is 1 joule equal to in calories?

250 calories in joules

All Images Shopping Videos News More Tools

Energy

250 = 1046

Gram calorie Joule

Formula multiply the energy value by 4.184

More info Feedback

People also ask

How much energy is 250 calories?

What is 1 joule equal to in calories?

What is the value of 259 calories in joules J?

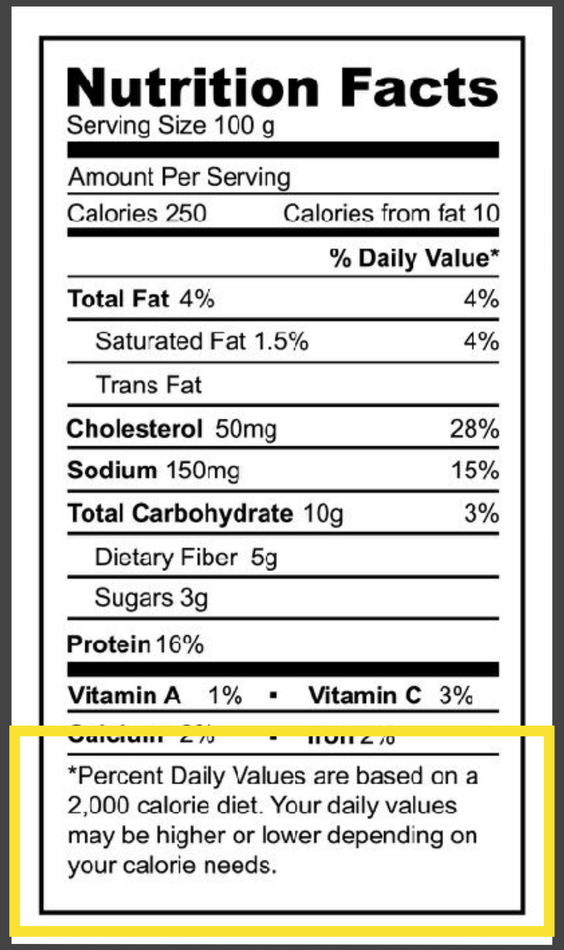
https://www.rapidtables.com › energy › Calorie_to_Joule

Highlights™

Look and Look Again

Can you spot the differences?

Activity: What did you eat today?



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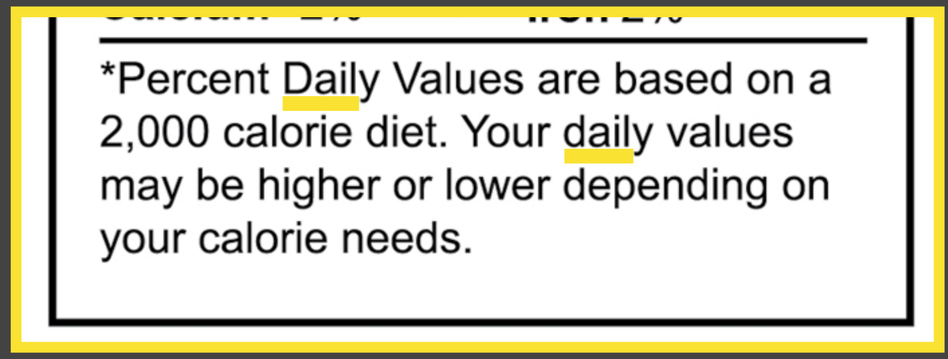


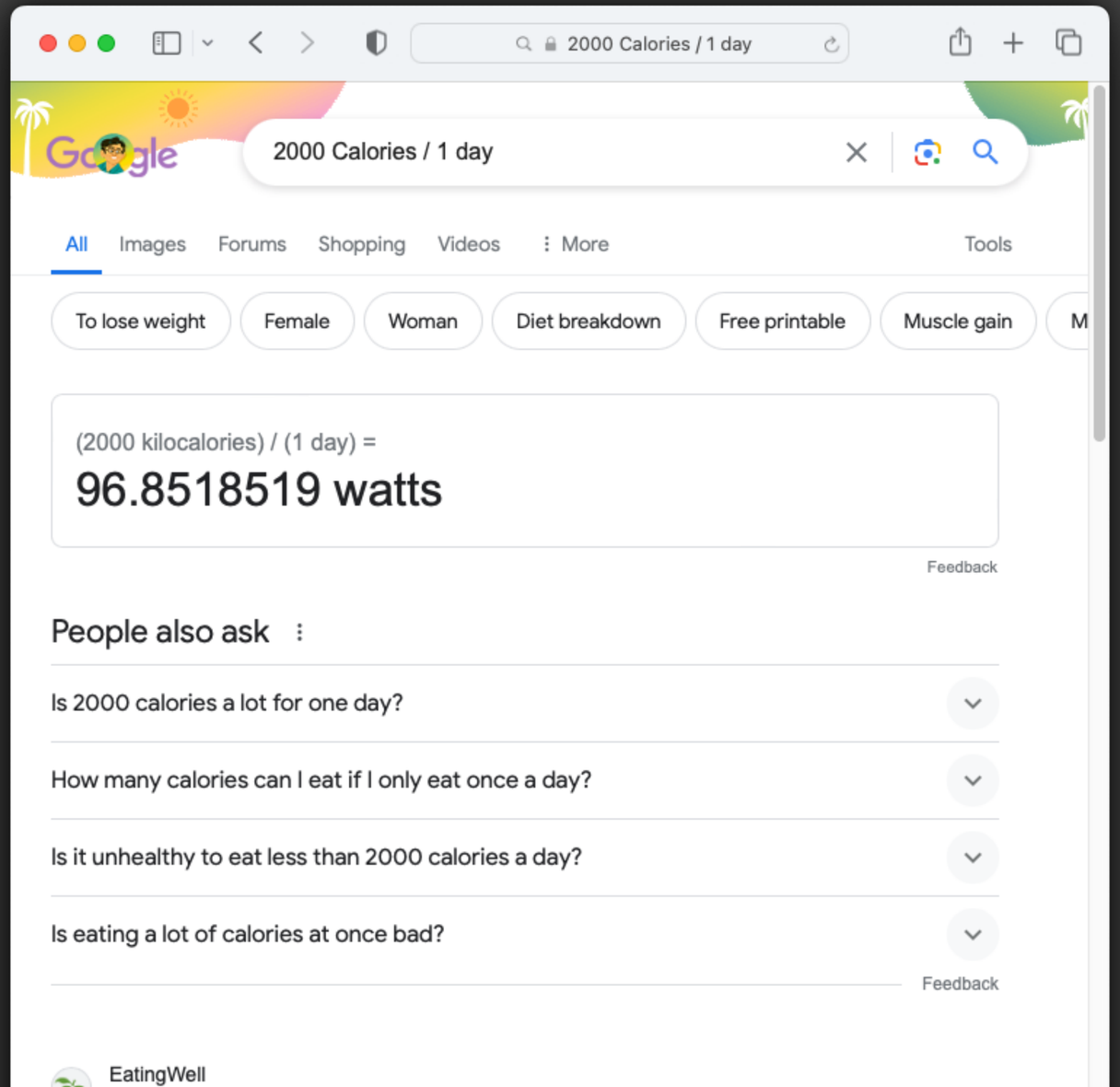
*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Note the term “daily” introduces a ***time period***

Activity: Calculate human power.

Activity: Calculate human power.

Try this: Using the same tools, divide an energy unit by a time unit. What do you get?



Joule = the SI unit for Energy

Watt = the SI unit for Power (J/s)

A Watt is a *RATE* (this is weird - the “per” is built in)

An electrical watt (Volts * Amps) is the same watt (the units work out!)

1 Volt * 1 Amp

1 Watt

Rate

1 Joule / second

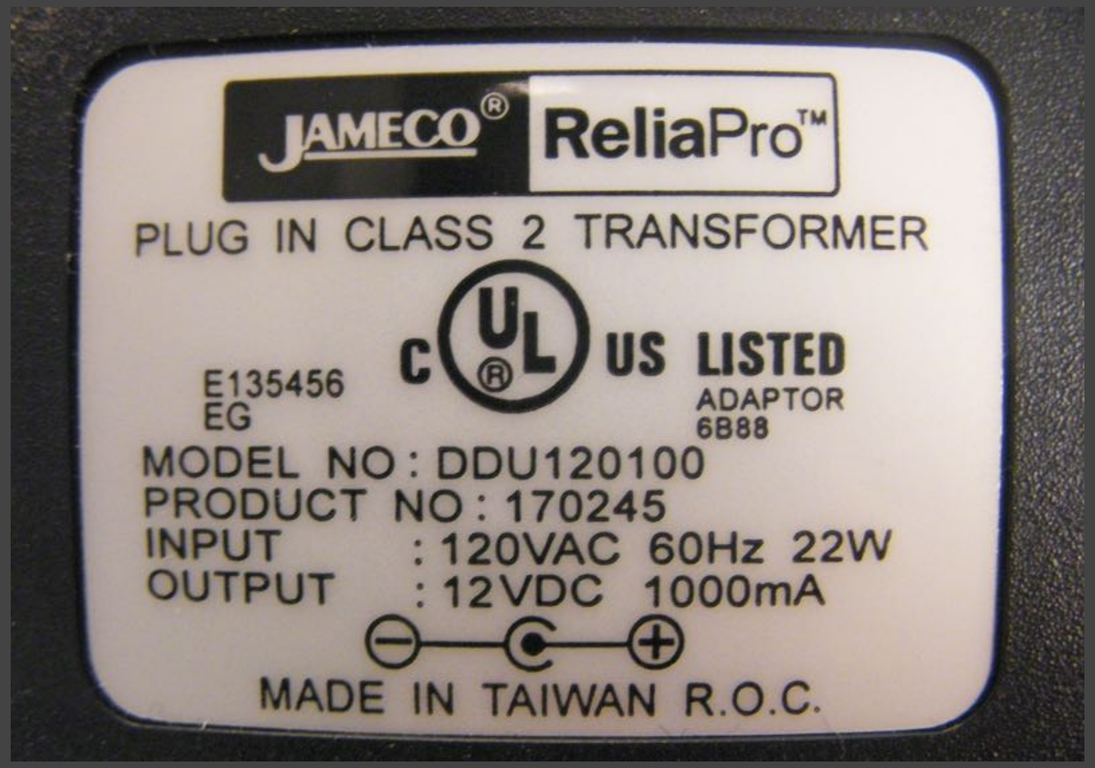
SI Energy Unit!

Time

What this means: We have a way to measure things with our multimeters that share units with every energy phenomenon in the universe

Activity: Energy scavenger hunt.

Activity: Energy scavenger hunt.



1. Take a picture of the power label on any electrical equipment at ITP.

2. Note its input power rating in watts. (If it only has volts and current, note that)

3. Imagine how the item is used. Is it on constantly all day every day? Is it used intermittently? Do you think it has various power level? Make reasonable guesses here.

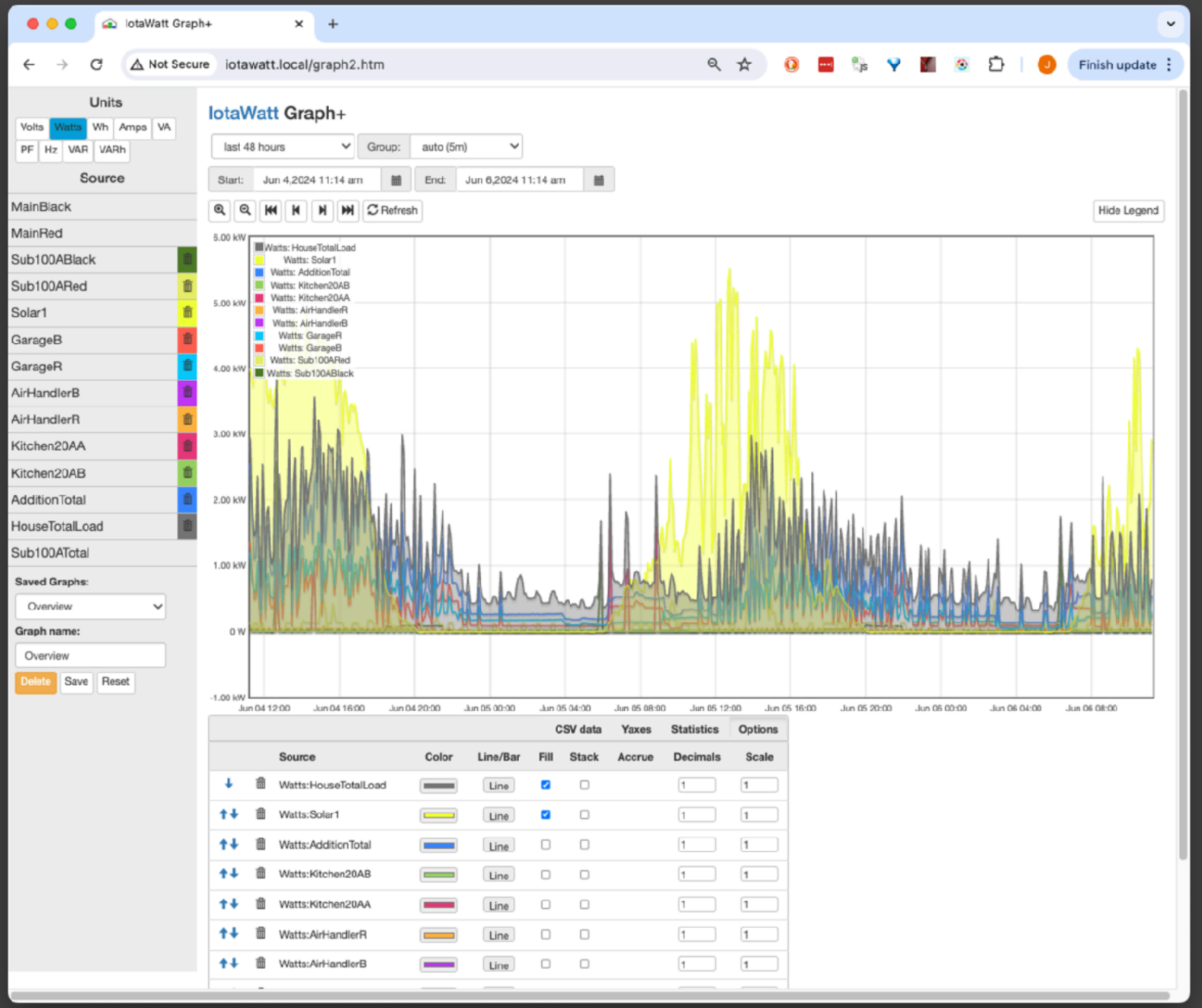
4. Report back here with your data and estimates.

Joule = the SI unit for Energy

Watt = the SI unit for Power (J/s)

- **Power = Energy/Time, and**
- **Energy = Power x Time**

The **watt-hour** is another unit for Energy, more common than joule in many applications (e.g. your power bill).


IotaWatt Graph+
iotawatt.local/graph2.htm
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Finish update
Units
Volts
Watts
Wh
Amps
VA
PF
Hz
VAR
VARh
Source
MainBlack
MainRed
Sub100ABlack
Sub100ARed
Solar1
GarageB
GarageR
AirHandlerB
AirHandlerR
Kitchen20AA
Kitchen20AB
AdditionTotal
HouseTotalLoad
Sub100ATotal
Saved Graphs:
Overview
Graph name:
Overview
Delete
Save
Reset
IotaWatt Graph+
last 48 hours
Group:
auto (5m)
Start:
Jun 4,2024 11:14 am
End:
Jun 6,2024 11:14 am
Refresh
Hide Legend
6.00 kW
5.00 kW
4.00 kW
3.00 kW
2.00 kW
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0 W
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Watts: HouseTotalLoad
Watts: Solar1
Watts: AdditionTotal
Watts: Kitchen20AB
Watts: Kitchen20AA
Watts: AirHandlerR
Watts: AirHandlerB
Watts: GarageR
Watts: GarageB
Watts: Sub100ARed
Watts: Sub100ABlack
Jun 04 12:00
Jun 04 16:00
Jun 04 20:00
Jun 05 00:00
Jun 05 04:00
Jun 05 08:00
Jun 05 12:00
Jun 05 16:00
Jun 05 20:00
Jun 06 00:00
Jun 06 04:00
Jun 06 08:00
CSV data
Yaxes
Statistics
Options
Source
Color
Line/Bar
Fill
Stack
Accrue
Decimals
Scale
Watts:HouseTotalLoad
Watts:Solar1
Watts:AdditionTotal
Watts:Kitchen20AB
Watts:Kitchen20AA
Watts:AirHandlerR
Watts:AirHandlerB
Line

IotaWatt Graph+

Not Secure iotawatt.local/graph2.htm

Finish update

IotaWatt Graph+

Units

Volts | Watts | Wh | Amps | VA | PF | Hz | VAR | VARh

Source

- MainBlack
- MainRed
- Sub100ABlack
- Sub100ARed
- Solar1
- GarageB
- GarageR
- AirHandlerB
- AirHandlerR
- Kitchen20AA
- Kitchen20AB
- AdditionTotal
- HouseTotalLoad
- Sub100ATotal

Saved Graphs: Overview

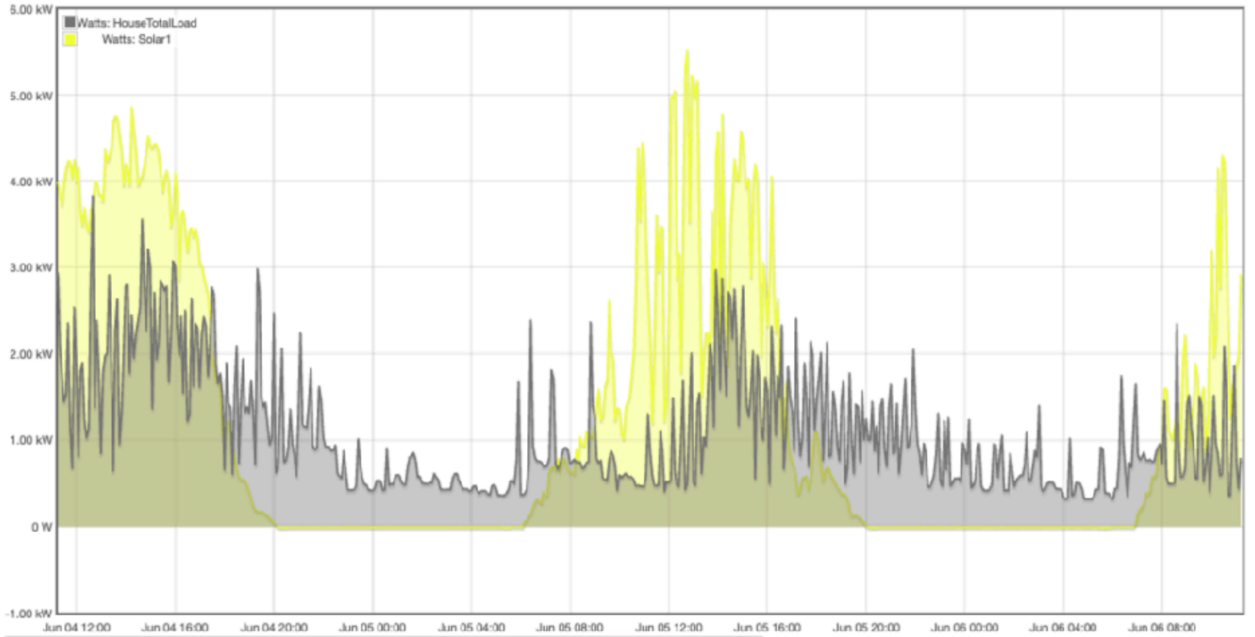
Graph name: Overview

Delete | Save | Reset

last 48 hours | Group: auto (5m)

Start: Jun 4,2024 11:14 am | End: Jun 6,2024 11:14 am

Refresh | Hide Legend



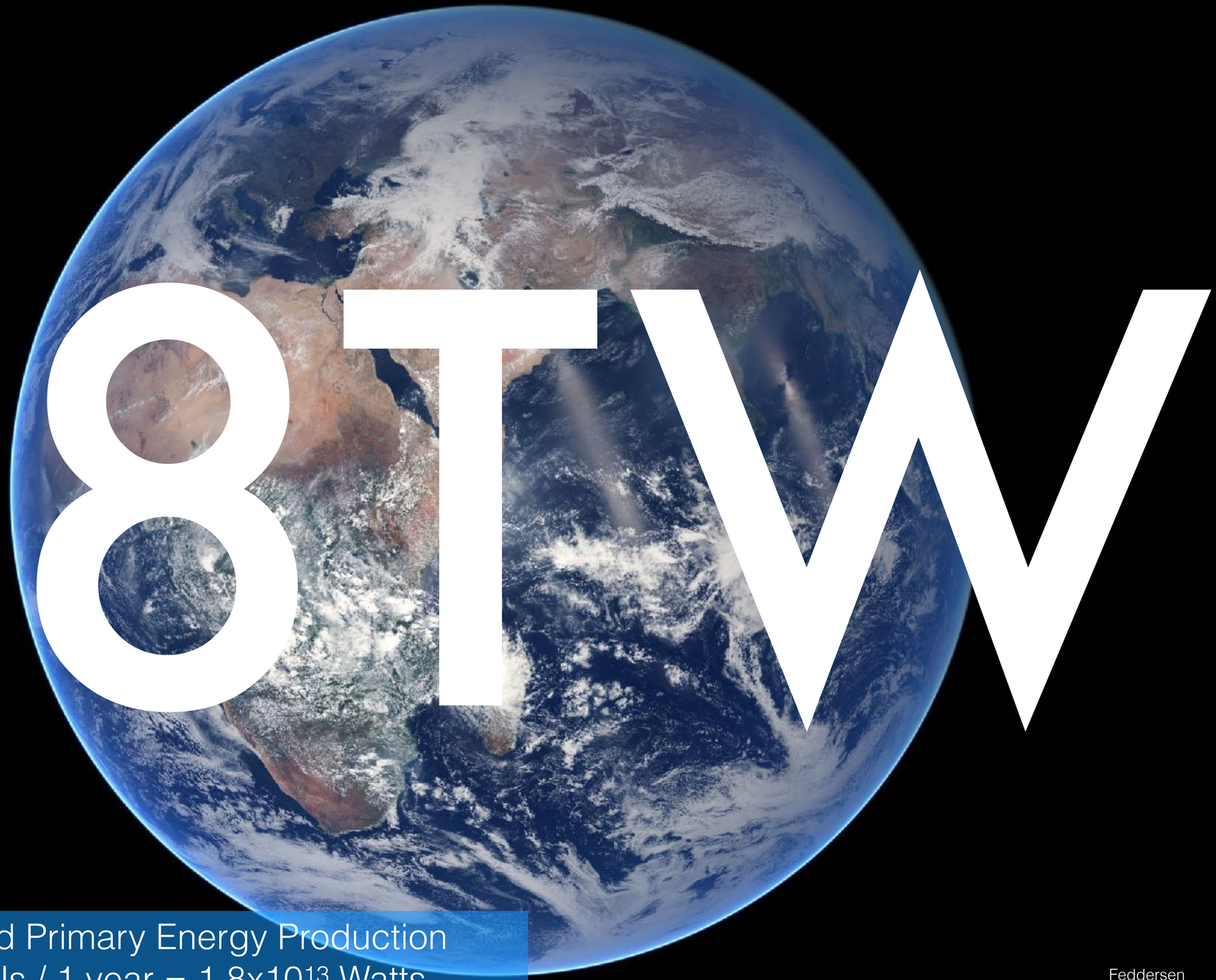
CSV data | Yaxes | Statistics | Options

Source	Quality	Min	Max	Diff	Average	Sum/Integral
Watts:HouseTotalLoad	100% (576/576)	317.4	3836.4	3519.0	1.08 kW	52.0 kWh
Watts:Solar1	100% (576/576)	-9.4	5517.4	5526.8	1.23 kW	58.9 kWh

itp CAMP

Conclusions:

- **Energy (joule or watt-hour) is important, but surprisingly tricky to pin down in everyday terms.**
- **Power (watt) is the rate of energy conversion** *(informally: "consumption")*.
- **Power is more familiar from every day life, especially electronics.**
- **Power = Energy/Time, and**
- **Energy = Power x Time**



18TW

Source: EIA Total World Primary Energy Production
~550 Quadrillion BTUs / 1 year = 1.8×10^{13} Watts

Feddersen
Energy NYU/ITP

TW GW MW kW W

18,000,000,000,000

(1.21 GW)

18TW

Feddersen
Energy NYU/ITP

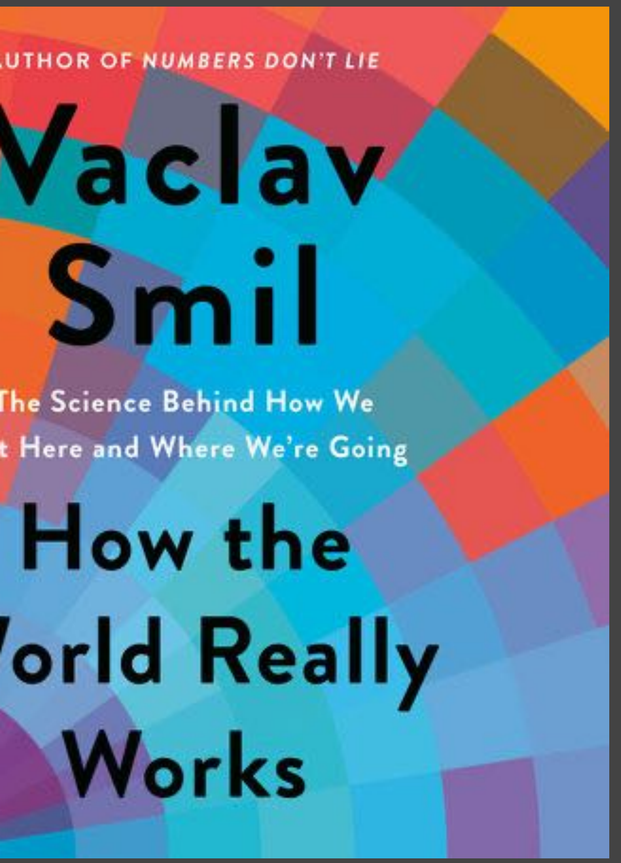
Understanding this is necessary
but insufficient...

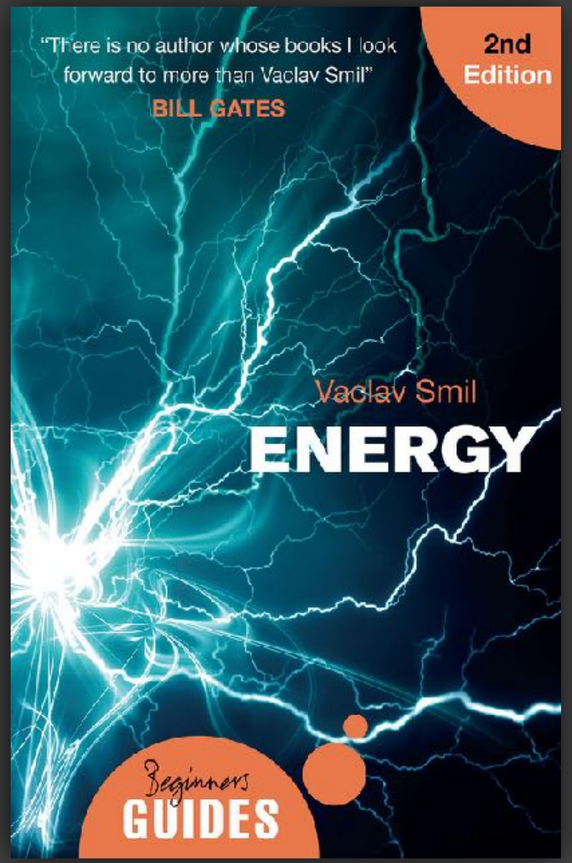
18TW

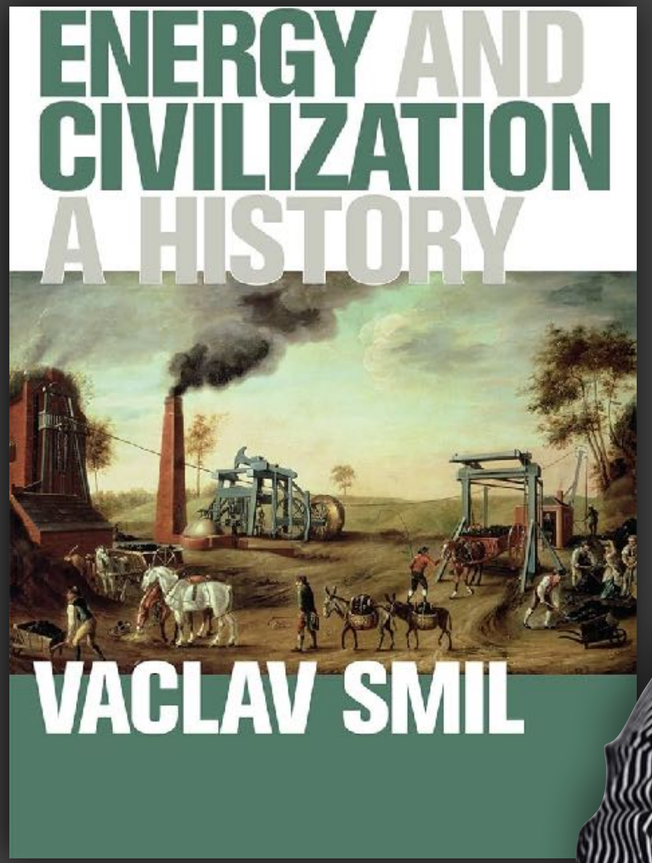
Feddersen
Energy NYU/ITP

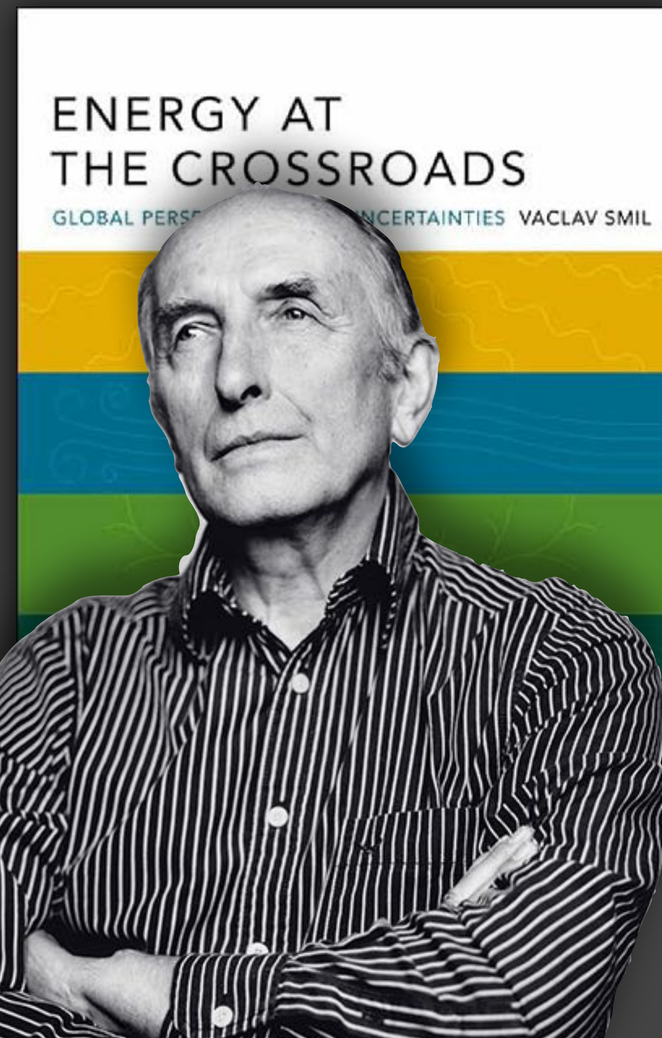
Further Resources

- Anything by Vaclav Smil



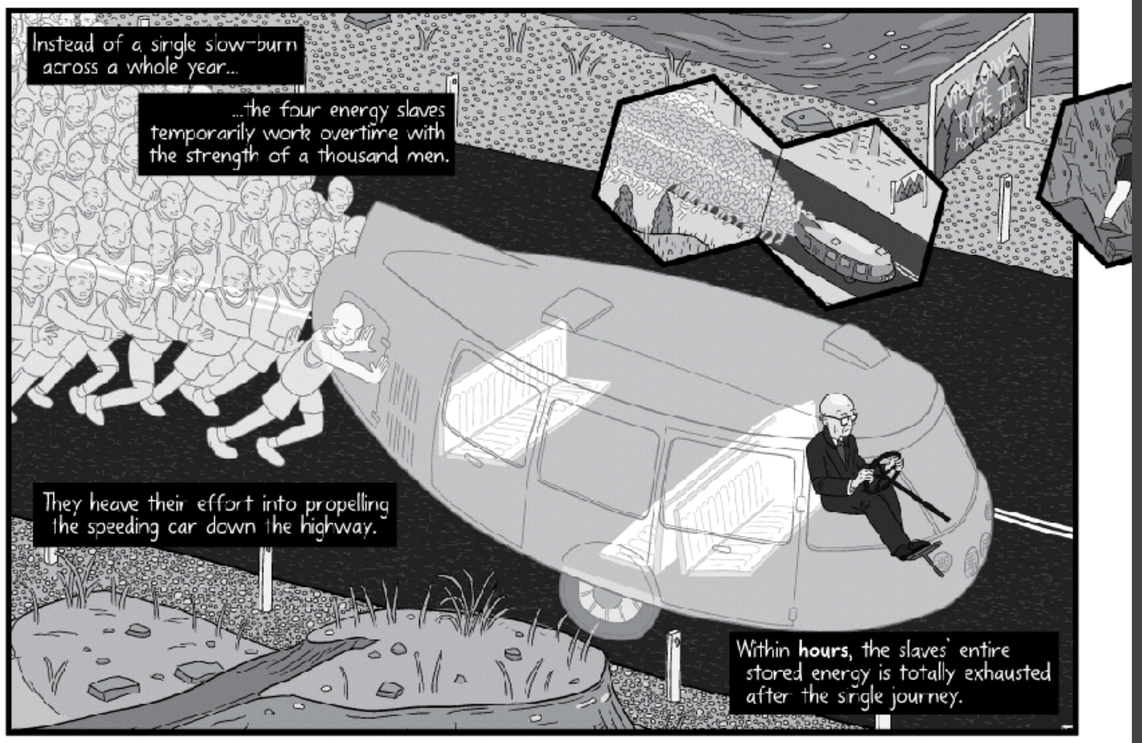


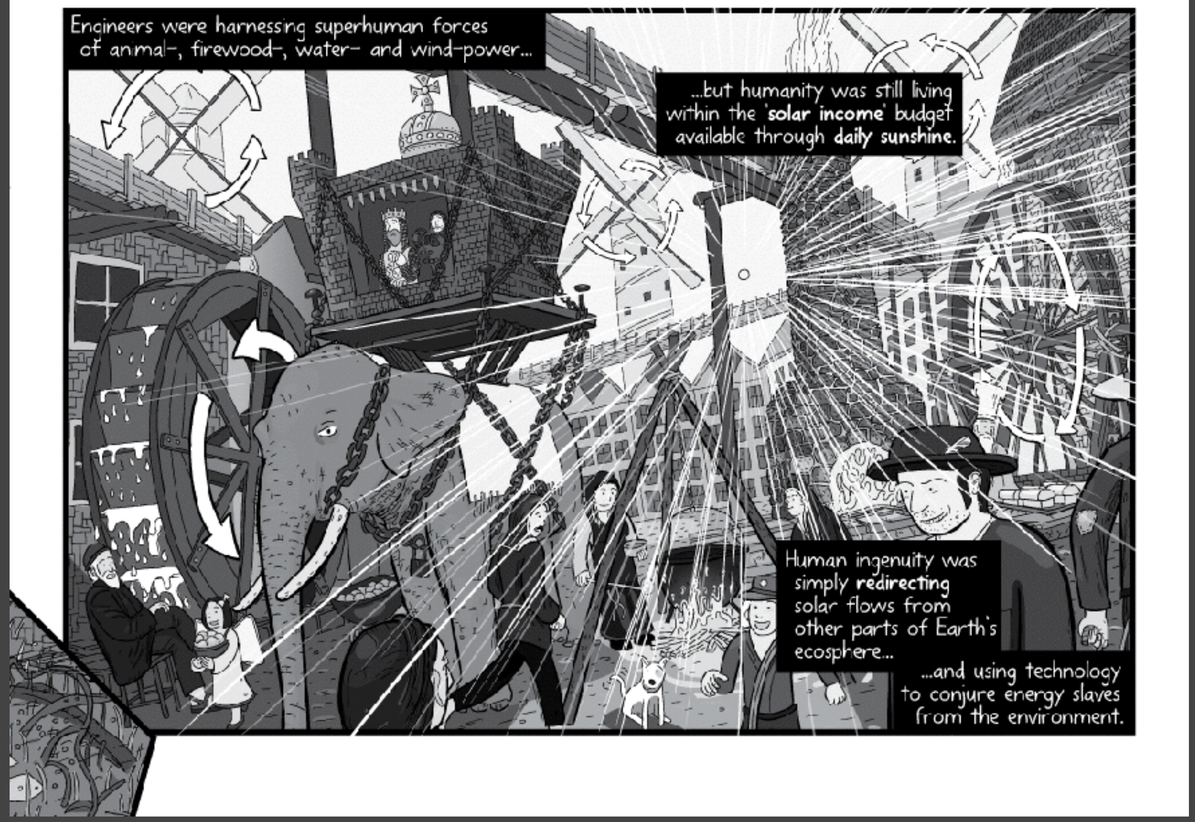




Further Resources

- Stuart McMillan on Buckminster Fuller





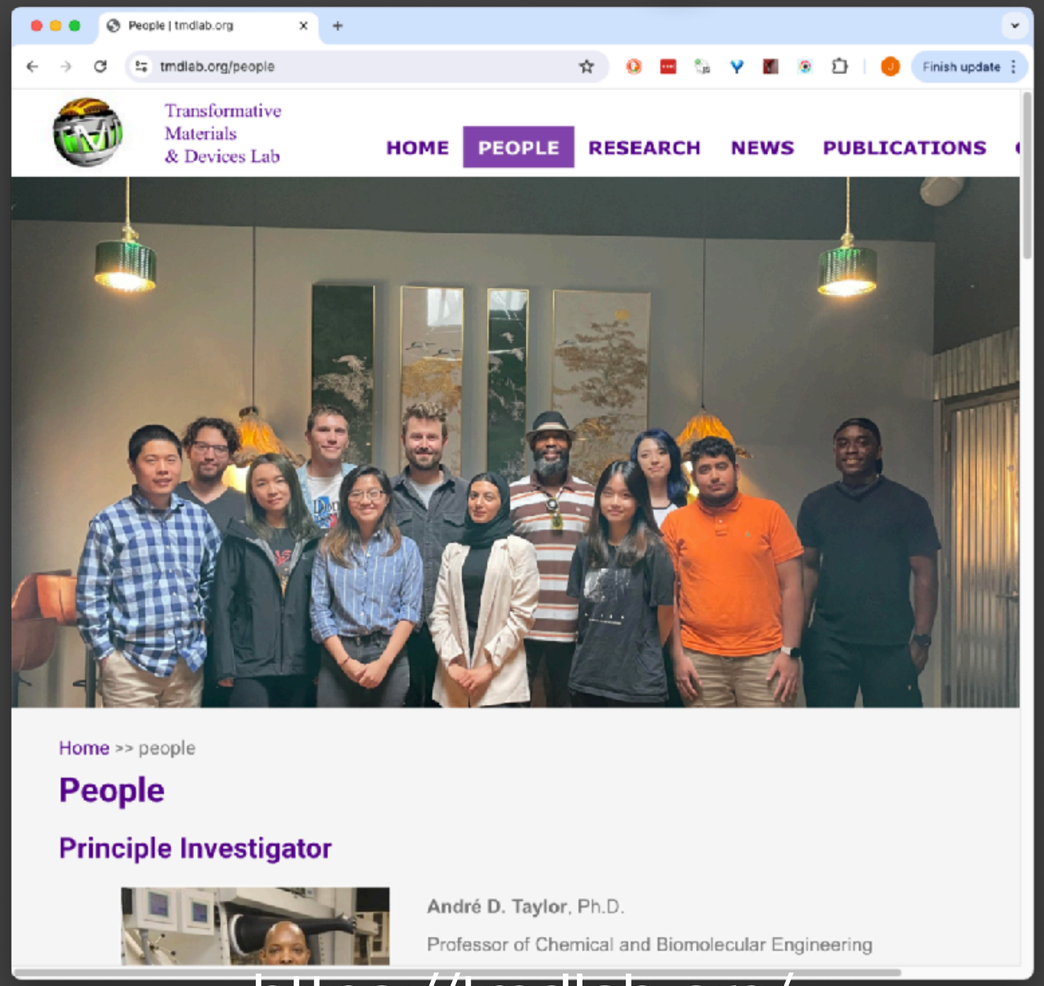
https://www.stuartmcmillen.com/comic/

Further Resources

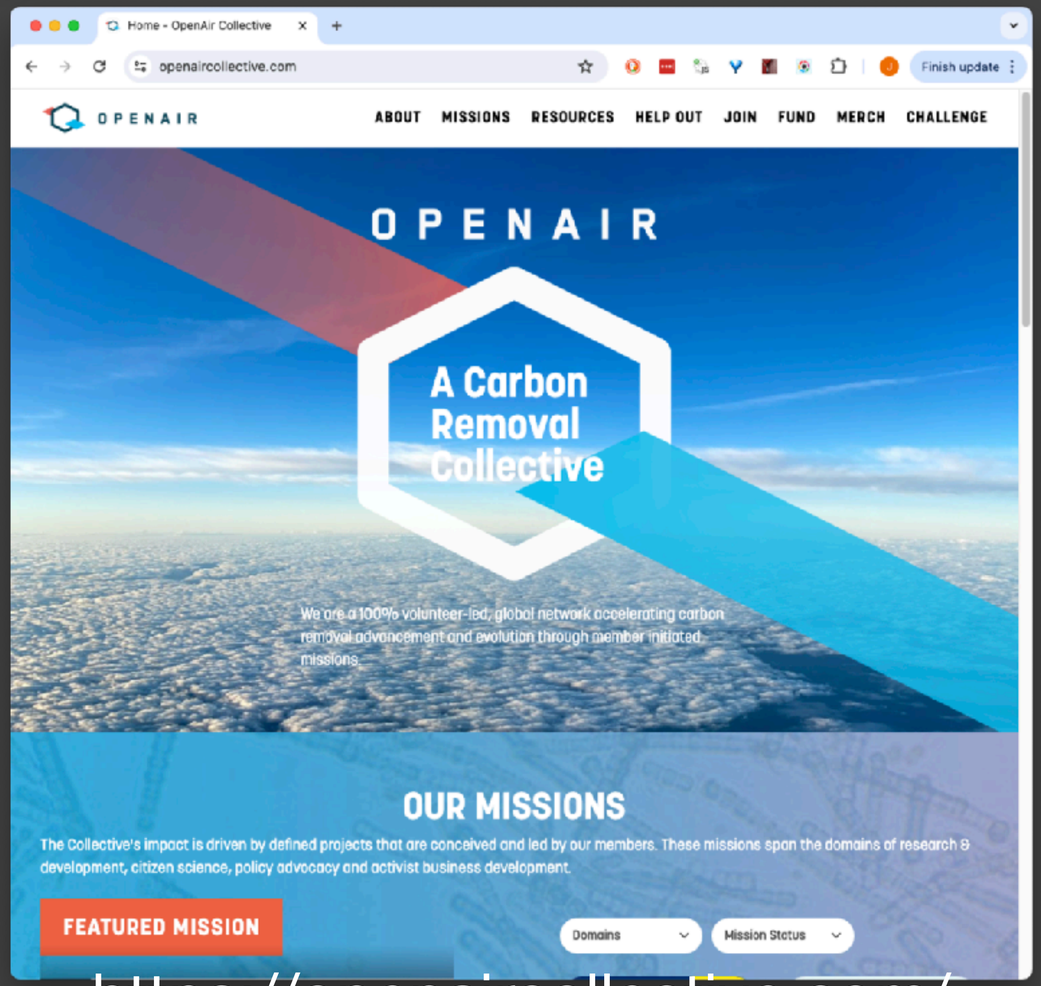
- Podcasts

Further Resources

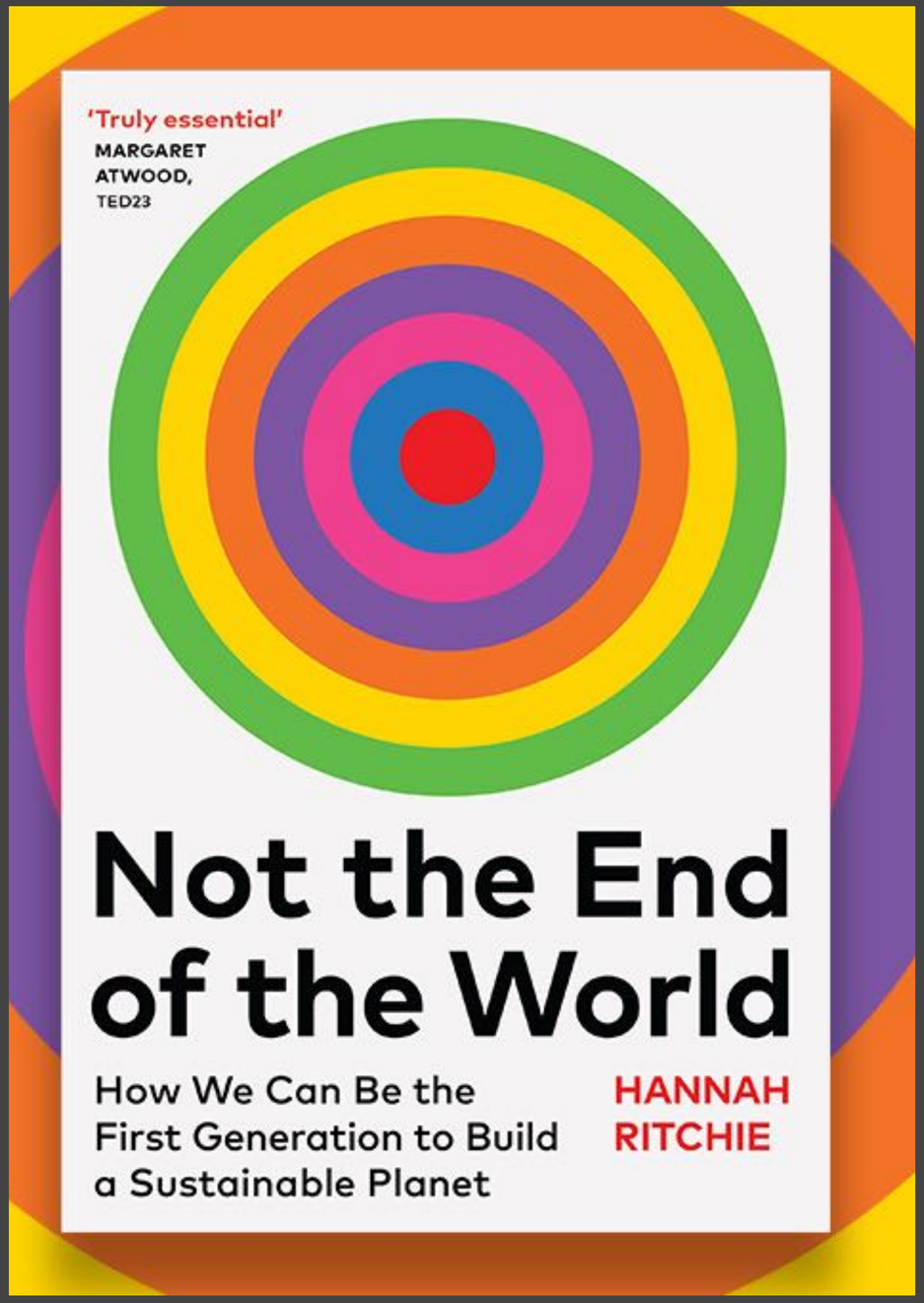
- Neighbors at NYU



https://tmdlab.org/



https://openaircollective.com/



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To make progress against the pressing problems the world faces, we need to be informed by the best research and data.

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FEATURED WORK

ARTICLE - 10 MIN READ

Is the number of natural disasters increasing?

A deep dive into missing data and the limitations of disa databases.

Hannah Ritchie and Pablo Rosado

Kinetic workshop, next week
Solar workshop, week after that

Feddersen
Energy NYU/ITP